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Development of offshore wind power in China

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ABSTRACT

China has strived to develop new and renewable energy resources to meet its energy demands due to issues of pollution, sustainability, and climate change related to the consumption of fossil fuels. Offshore wind power development in coastal China has attracted more and more attention because it can not only utilize the abundant natural resources but also relieve power constraint in coastal China. This paper studies the development of offshore wind power in China, providing information including the wind resources in China's coastal areas, policies promulgated by the central government to favor the sound development of offshore wind power, regional planning and progress of offshore wind power, R&D of offshore wind power technology and theory, as well as the pilot projects set up in Shanghai and Jiangsu. In addition, challenges related to offshore wind power development are depicted, and recommendations are provided.

Contents

1. Introduction

Energy demand due to the rapid economic growth has made energy issue become a priority in the governmental agenda in China. China's energy supply has heavily relied on fossil fuels, especially the coal. However, due to issues of pollution, sustainability, and climate change related to the consumption of fossil fuels, China has tried its best to divert its energy supply from traditional energy resources, such as fossil fuels, to new energy resources, including nuclear power and renewable energy, such as hydro, wind and solar power. Among the new energy resources, wind power has gradually become more attracted due to the following reasons. First, wind power is safer compared with the nuclear power. Second, the development cost of wind power is cheaper compared with solar energy. Third, wind power technology is more mature compared with biomass. Fourth, wind power has larger industrial scale compared with ocean energy [1]. China has favorable natural conditions for the utilization of wind power. Since China's first pilot onshore wind power farm established in Shandong Province in 1986 [2], onshore wind power has developed rapidly, mainly in north China [3,4]. In recent years, onshore wind power development in China is relatively mature and the attention has gradually shifted from onshore to offshore wind power development. Compared with onshore wind farms, offshore wind farms do not have to

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occupy large land resources. China has a long coastal line with abundant wind energy resources. Coastal areas, such as coastal mudflats and inshore zones, possess good conditions for wind power development [5]. A preliminary estimate indicates that the potential installed capacity is approximately 200 GW at the height of 50 m above the sea level in the inshore areas within the water depth of 5–25 m [6]. Regions along the coastal line in eastern China have faster economic growth than regions in western China thus coastal China is the major electricity demand region. If large-scale offshore wind farms can be built along China's coastal areas, long-distance electricity transmission from western to eastern China is no longer necessary. To fully utilize the advantage of clean natural resources in eastern China can relieve the electricity constraint in coastal areas as well as effectively tackling climate change [5]. According to the development plan, China is going to build 5 GW installation capacity during the 12th Five-Year Plan (2011-2015), and wind power construction in China will enter a new stage of comprehensive development of both onshore and offshore wind power [7].

2. Wind resources in coastal China

According to the data from China Meteorological Administration, offshore wind power resources reach over 750 GW, much more than the potential hydro power resources of 378 GW [8,9]. Fig. 1 shows 50 m wind map in coastal China.

Wind energy resources in the coastal areas of China are classified into two categories [6]:

(1) Wind-energy abundant belt in the coastal areas and their related islands: Coastal areas and their related islands include 10-km-broad coastal areas of Hainan, Guangxi, Guangdong, Fujian, Zhejiang, Shanghai, Jiangsu and Shandong, with annual wind power density above 200 W/m^2, and wind power density contour is parallel with the coastline.
(2) Inshore wind-energy abundant areas: Coastal areas in eastern China have vast sea areas within the sea water depth of 5-20 m, although the capacity of technically exploitable inshore wind energy resources in practice is much smaller than on land due to the constraints of sea function division including ship route, harbor, and aquaculture. However, areas in Guangdong, Fujian, Jiangsu and Shandong have abundant inshore wind energy resources which are close to centers of major electricity demand, thus inshore wind power can become key clean energy for the future development of these areas.

Wind farms are classified into onshore and offshore wind farms by the National Energy Administration. Offshore wind farms include mudflat wind farms in the intertidal and subtidal zones, inshore wind farms, and deep-sea wind farms. Detailed classifications are as follows [6]:

(1) Onshore wind farms, refer to those established on land and in supratidal mudflat areas above the average high tidal line in coastlands, including those established on islands with permanent residents.
(2) Mudflat wind farms in the intertidal and subtidal zones, refer to those established in sea areas below the average high tidal line in an up to 5-m water depth at the theoretically lowest water level in the coastal areas.
(3) Inshore wind farms, refer to those established in the sea areas of 5–50-m water depth below the theoretically lowest water level, including those established on islands without permanent residents and reefs within the corresponding sea areas.
(4) Deep-sea wind farms, refer to those established in the sea areas with a water depth of 50 m or more below the theoretically lowest water level, including those established on islands without permanent residents and reefs within the corresponding sea areas.

3. Policies related to offshore wind power development

In 2005, the National Development and Reform Commission (NDRC) issued *Directory of Renewable Energy Industry Development* in which research projects of inshore wind power technology were listed as priorities supported by the state [11]. Projects related to inshore wind power technology were listed in Table 1. It indicates that compared with inland wind power industry which has already reached preliminary stage of commercial scale, inshore wind power industry still focuses on technological R&D.

In August 2007, the *Mid- and Long-Term Development Plan of Renewable Energy* was issued. It proposed to build one or two pilot projects of 100 MW-scale offshore wind farms by 2010 and establish 1000 MW-scale offshore wind farms by 2020 [12]. In 2007, the *11th Five-Year Plan of Renewable Energy Development* was issued by the NDRC. The plan proposed to strengthen the research on technology of developing offshore wind power, carry out preliminary preparation for exploration and evaluation of offshore wind power, and pilot demonstration projects, and establish one or two pilot projects of 100 MW-scale offshore wind farms, so as to accumulate experience for the development of large-scale offshore wind farms. In the plan, coastal areas which are suitable for wind farm development are classified into two major categories: key areas and general areas [13]. Table 2 shows regional layout of wind power projects of key and general areas.

On January 15, 2009, the National Energy Administration held the *Seminar on the Development of Offshore Wind Power and Construction of Coastal Large-scale Wind Power Bases*. Related departments at the central and local levels, scientific research institutes, companies and organizations took part in the seminar. The chief of the National Energy Administration indicated that to promote the initial work for offshore wind power development, several tasks need to be done in recent periods, including choosing several sites which are fit for the development, completing utilization plans of land and sea areas and environmental impact assessment, improving wind measurement and resource evaluation, and determining enterprises for the development and investment of offshore wind power [14].

In addition, the chief of the National Energy Administration of the NDRC indicated that related departments would carry out the deployment of offshore wind power plan and construction. The plan will focus on three main aspects. First is to formulate an administrative regulation. The national administrative procedures of onshore wind power are relatively thorough and normative while offshore wind power is at the initial stage. Offshore projects involve regulatory departments different from those of onshore wind power projects thus new procedures need to be established and authorities and administrative permission of various departments need to be clearly defined. Second is to make a regional plan. China has a long coastline. Some regions are fit for harbor development while some are fit for offshore wind power development. Therefore, coastal areas which are fit for offshore wind power development should be identified and functions among coastal areas should be clear defined. Third is to deal with technological difficulties of offshore wind power. Compared with onshore wind power, the operating environment of offshore wind power is more complex with higher demand for technology and more difficulties in construction. According to the pilot demonstration projects, the current difficulties are construction, offshore wind power

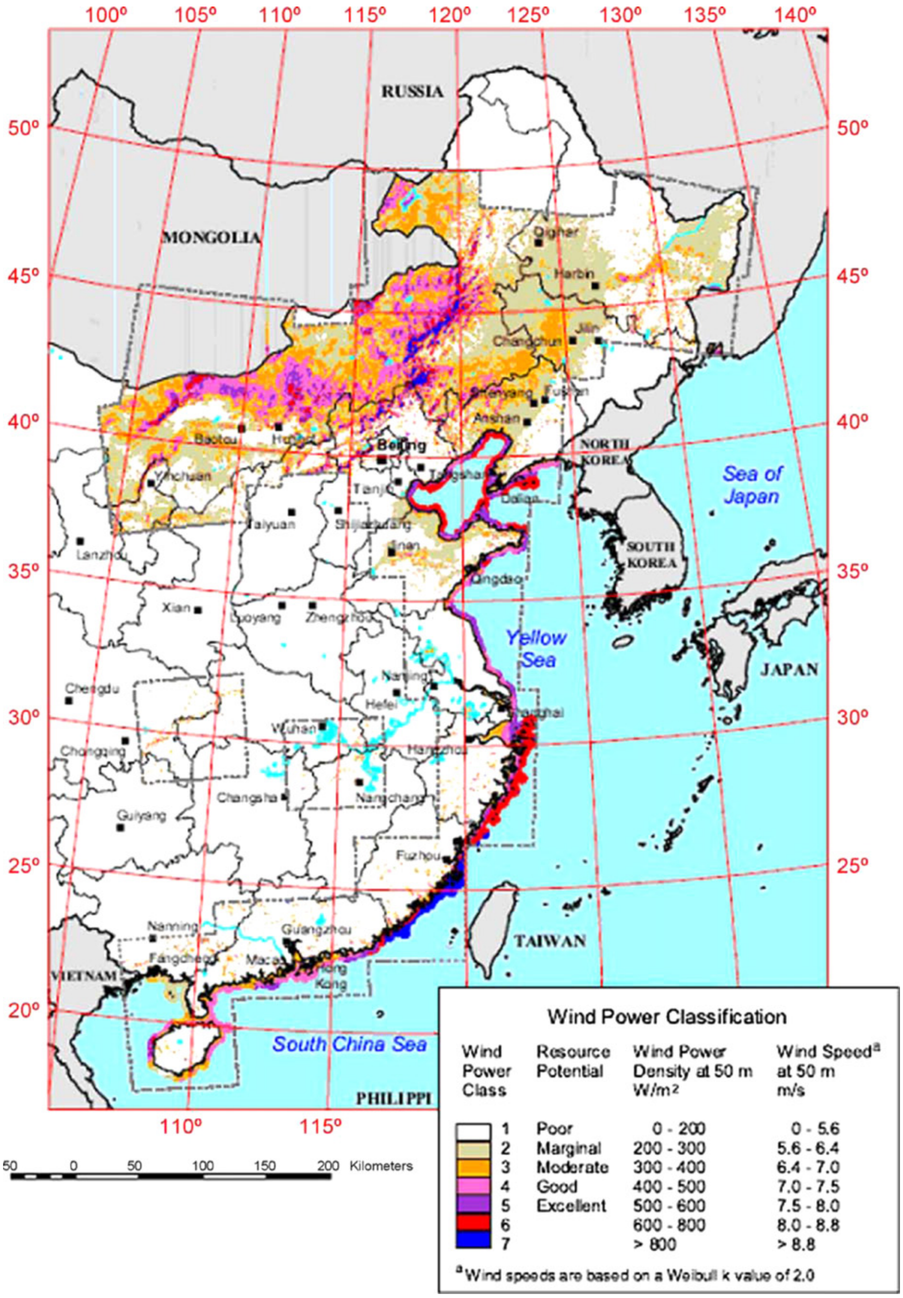


Fig. 1. 50 m wind map in coastal China.

Source: [10]

Table 1
Projects related to inshore wind power technology [6,11].

Project	Instruction and technological index	Development status
Grid-connected wind power generation	It is used for supplying electricity for the power grid, including onshore and inshore grid-connected wind power generation, single or multi-machine grid-connected power generation.	Onshore grid-connected wind power generation: initial stage of commercialization; inshore grid-connected wind power generation: technical R&D
Exclusive equipments for wind farm construction and maintenance	They are used for transporting, on-site hoisting and maintaining onshore and inshore wind turbine generator system (WTGS).	Technical R&D
Grid-connected wind turbine generator system (WTGS)	It is used for grid-connected wind power generation, including onshore and inshore wind turbine generator system (WTGS). Inshore wind turbine generator system (WTGS) is required to adapt to conditions of sea geography, hydrology and climate.	Onshore wind turbine generator system (WTGS): initial stage of commercialization; offshore wind turbine generator system (WTGS): technical R&D

Table 2
Regional layout of wind power projects [13].

Category	Region	Scale (10 MW)		Project layout (location)
		Under construction	Accumulated production	
Key areas	Coastal areas of Jiangsu and Shanghai	200	100	Wind farms in Rudong, Dongtai, Dafeng and Qidong of Jiangsu; wind farms in Congming and Nanhui of Shanghai;
General areas	Shandong	60	20	Jimo, Qixia, Weihai, Dongying, etc.
	Guangdong	60	30	Huilai, Nan'ao, Jiadong in Lufeng, Xuwen, Chuandao, etc.
	Fujian	40	20	Pingtan, Putian, Zhangpu, Gulei, ect.
	Zhejiang	25	10	Daishan, Cangnan, Cixi, ect.

Note: The scale includes onshore and offshore wind farms. Wind farms in Qixia in Shandong are onshore wind farms. Wind farms in Chuandao in Guangdong and in Gulei in Fujian are not clear whether offshore wind farms are included or not.

transmission and distribution, and wind turbine generator system of anti-corrosion and anti-salt spray. However, these difficulties can only be resolved in practice [5].

The seminar was a milestone for the central government to determine the implementation strategy of offshore wind power development and make substantive arrangement for related preliminary work. Technological standards were issued at the seminar, including *Preparation Rules for Reports on Inshore-wind-farm Engineering Planning (Trial)* and *Preparation Rules for Reports on the Prefeasibility Study of Inshore-wind-farm Engineering (Trial)* [6].

On January 22, 2010, the National Energy Administration and the State Oceanic Administration jointly issued the *Provisional Rules for the Administration of Offshore Wind Power Development*. It aims at regulating offshore wind power projects, promoting rational utilization of spacial resources of sea areas, strengthening eco-environmental protection of seas, and guiding sound and sustainable development of offshore wind power. It covers administrative institution management and technical quality management in procedures including offshore wind power development planning, project grants, project approval, sea-area utilization, marine environment protection, acceptance of construction and completed construction, and operating information management. Management bodies were stipulated in the provisional rules: competent national energy departments take charge of the management of national offshore wind power development; competent energy departments of various provinces/autonomous regions/municipalities in the coastal areas take charge of the management of local offshore wind power development under the guidance of competent national energy departments; departments responsible for managing national wind power construction technologies take charge of the management of offshore wind power technology. The promulgation of the provisional rules indicates that the Chinese government has embarked on the management and monitoring of scale-development of offshore wind power at the national level [6,15].

To guide the sound development of wind-power equipment manufacturing industry and avoid aimless expansion of wind-power equipment capacity, *Entry Standards for Wind-power Equipment Manufacturing Industry (Draft for Comments)* was issued by the Ministry of Industry and Information Technology on March 25, 2010. It clearly indicates that the development of industrial scale of offshore wind turbine generator system will be prioritized [16].

Development Plan for Burgeoning Energy Industry was sent to the State Council for approval in October 2010 [17]. According to the plan, national wind power installation capacity is expected to reach 90 GW by 2015, with offshore wind power 5 GW; by 2020, national wind power installation capacity is expected to reach 150 GW, with offshore wind power 30 GW [18]. New 1 GW offshore wind power project in Jiangsu will be started and offshore wind power development in Hebei, Shandong, Zhejiang, and Fujian will be promoted. The construction of the second phase of offshore wind farm project of Shanghai's Donghai Bridge will be speeded up as one of the major wind power projects which the central government plans to start in 2011 [19,20]. In the coming period of the 12th Five-Year Plan, China will support critical technologies of wind turbine generator system, including 5 MW offshore wind turbine generator system, as well as key technologies for inshore wind power [21].

4. Regional planning and progress

Shanghai, Jiangsu, Guangdong, Fujian, Zhejiang, Shandong, and Liaoning are all under the planning of offshore wind power development. Jiangsu, Shanghai, Guangdong, and Shandong have relatively comprehensive planning. However, due to lack of support for offshore wind energy resources assessment and analysis, planning from these provinces/municipalities still remains on hold [6]. Table 3 shows progress in offshore wind power planning by province/autonomous region/municipality.

According to the preliminary plans from various provinces/municipalities, without considering the capacity of market consumption, in provinces/municipalities including

Table 3
Progress of offshore wind power development planned by province/autonomous region/municipality [6].

Province/Autonomous region/Municipality	Progress
Shanghai	Passed the review
Jiangsu	Complete the review and enter the stage of revision and improvement
Zhejiang	Complete the application for review and wait for review
Shandong	Complete the draft and enter the stage of further improvement
Fujian	Complete the draft and enter the stage of further improvement
Hebei, Liaoning, Guangxi, Hainan, Guangdong	Planning report in preparation

Table 4
Planning capacity for offshore wind power development by province/autonomous region/municipality [6].

Province/Autonomous region/Municipality	Planning capacity (MW)	
	Year 2015	Year 2020
Shanghai	700	1,550
Jiangsu	4,600	9,450
Zhejiang	1,500	3,700
Shandong	3,000	7,000
Fujian	300	1,100
Other (tentative)	5,000	10,000
Total	15,100	32,800

Note: For Jiangsu, planning capacity by 2015 includes 2000 MW in inshore areas and 2600 MW in intertidal areas while planning capacity by 2020 includes 6550 MW in inshore areas and 2900 MW in intertidal areas [22].

Jiangsu, Shanghai, Shandong, Zhejiang, and Fujian, the planned installed capacity of offshore wind power reaches 10,100 MW by 2015, among which inshore wind power 5900 MW, and wind power in intertidal zones 4200 MW; the planned installed capacity of offshore wind power reaches 22,800 MW by 2020, among which inshore wind power 17,700 MW, and wind power in intertidal zones 5100 MW [6]. Table 4 shows the planning capacity for offshore wind power development by province/autonomous region/municipality.

5. R&D of offshore wind power technology and theory

5.1. Offshore wind power technology

Key technologies of offshore wind farms include those related to foundations, selection of site, wind measurement, investigation, wind turbines of offshore wind farms, hoisting, electrical transmission technology, and access and stability operation of system (detailed information can refer to Ref. [23]. Although China is equipped with wind farm development experience, most of the experience is limited to onshore wind power. Offshore wind power is new to China, thus key technologies related to basic design, construction, facilities and operation are vital before the large-scale development. Therefore, the Ministry of Science and Technology of China allocated special funds to support related departments to develop R&D of key technologies of inshore wind power during the 11th Five-Year Plan. Projects for inshore wind power supported by the Ministry of Science and Technology of China include research on key technologies in the construction of inshore wind farms, development of special facilities for installation and maintenance of inshore wind turbine generator system, technical and economic analysis of inshore wind farms and their environmental impact assessment, technical manual of inshore wind farm construction, and R&D of 3 MW offshore wind power facilities with proprietary intellectual property rights [6].

5.2. Non-grid-connected wind power generation theory

The general way to utilize wind energy is to connect wind power to the thermal power grid. However, due to the intermittence and instability of wind power, grid-connected wind power can have certain adverse impact on the grid and reduce the quality of the electricity. Non-grid-connected wind power theory can serves as a way to counter the disadvantages of using wind power. Non-grid-connected wind power generation refers to that the load terminal of the wind power is not traditional thermal power grid but certain commercial or industrial application which can directly consume the wind power. These special consumers are electricity-consuming and able to accept fluctuated electricity [24].

The theory is created by Gu Weidong, dean of Macro-economy Research Institute in Jiangsu. The driving force for the creation of the theory is to make good use of the abundant wind resources in coastal and offshore areas in Jiangsu. According to Jiangsu's current industrial development conditions, the theory can be directly applied to some special industries, including seawater desalination industry, chlor-alkali and PVC industry, non-ferrous metallurgy industry focusing on electrolytic aluminum, and new green coal chemical industry [25,26]. China's first non-grid-connected wind power diverse application, a demonstration project of seawater desalination using wind power, was established at the end of January 2011. The project can generate 100 tons of fresh water and 120 m^3 of hydrogen. The conductivity of fresh water generated by the wind power reaches national pure-water standard and the purity of hydrogen reaches 99.99% [27]. At the *Seminar of Seawater Desalination and China's Coastal Economic Development Strategy in the 12th Five-Year Plan and the Achievement Assessment Meeting of Seawater Desalination by Non-grid-connected Wind Power*, an official from the Ministry of Science and Technology of China indicated that the government hopes to achieve seawater desalination in eastern coastal waters through departmental and provincial cooperation, promote the establishment of a 100-billion-yuan-scale outfit manufacturing base in coastal areas, and make non-grid-connected wind power achieve industrialization and diversification [28].

6. Establishment of offshore wind farms in China

6.1. Shanghai

Shanghai is located at 31° north latitude which belongs to mid-latitude regions. Located in the western Pacific Ocean and being China's Yangtze River estuary, Shanghai has a great potential for the development of offshore wind power generation [23]. Seven-year wind measurement results show that at the height of 50 m at the coastal areas of Donghai, average wind speed reaches 7.1 m/s, with average effective wind energy 329 W/m^2 and accumulated time of annual effective wind power 7300 h. It is estimated that Shanghai has a potential offshore wind energy resources of 4700 MW. Moreover, Shanghai has shallows for installation of large-scale wind turbine generator system, thus Shanghai possesses natural conditions for wind power development [29].

Offshore wind farm project of Shanghai's Donghai Bridge is the first offshore wind farm in China. It is located along a line 1,000 m away from both sides of Donghai Bridge, which connects the Yangshan deep-water port with Lingang New City. Its southernmost end is 13 km from the coastline and the northernmost end is around 6 km away from the coastline of Nanhuizui. The wind farm is within sea areas in Shanghai. The average depth of the waters in the wind farm is 10 m with annual average wind speed 8.4 m/s at the height of 90 m. Donghai Bridge Wind Farm is composed of a wind turbine generator system (WTGS) of thirty-four 3 MW single machines. Total project investment is 2.365 billion yuan. Its total installed capacity is 102 MW and the designed annual power generation utilization hours reach 2,624 h, with an expected annual electricity output of 267 GWh. This will meet the annual demand of 200,000 average families [6,30] and lead to 246,058 tons of CO_2 emission reduction per year [31]. The project developers, Shanghai Donghai Wind Power Co. Ltd., a company formed by China Power International Development Ltd., Datang, China Guangdong Nuclear Power Group and Shanghai Green Energy, are undertaking the management, construction, operation and maintenance of the wind farm [6,30]. The project began its construction in April 2008 and became operational in July 2010. On 29 March, 2011, the project passed the acceptance check, which indicates a breakthrough in China's offshore wind power development. The project can offer valuable experience for China's future offshore wind power development [32,33].

According to the national mid- and long-term development plan of wind power, Shanghai formulated *Plan of Shanghai's Wind Farm Locations and Installed Capacity 2020*, which has been incorporated

Table 5
Planned locations and installed capacity of Shanghai's offshore wind power development [8].

Wind farm project	Location	Planned installed capacity (MW)
Donghai Bridge offshore wind farm	Nanhui district	200
Nanhui offshore wind farm	Nanhui district	100
Fengxian offshore wind farm	Fengxian district	500

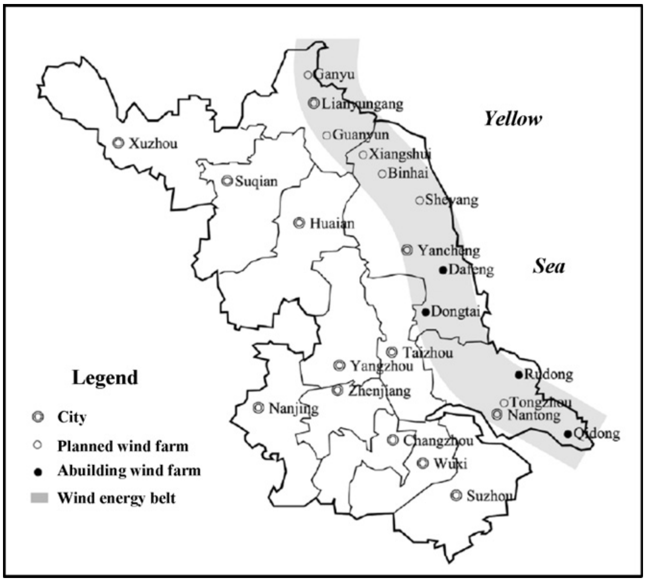


Fig. 2. The distribution of wind farms in Jiangsu Province.
Source: [24]

into the master plan of Shanghai's urban development [8]. Table 5 shows the planned locations and installed capacity of Shanghai's offshore wind power development.

6.2. Jiangsu

Jiangsu has abundant wind energy resources, especially at the eastern coastal areas. Along the eastern coast, the average wind speed at 50 m is up to over 6.4 m/s, the density of effective wind energy at 50 m is more than 150 W/m^2, and the average annual hours of effective wind energy are 5400 h [24]. Jiangsu's potential capacity of inshore wind power is around 18,000 MW. According to the *11th Five-Year Plan and Outlook 2020 of Jiangsu's Wind Power*, Jiangsu's wind power installed capacity will reach 10,000 MW by 2020, with onshore wind power 3,000 MW and inshore wind power 7,000 MW. In the long term, the wind power installed capacity will reach 21,000 MW with onshore wind power 3,000 MW and inshore wind power 18,000 MW [34].

Jiangsu has planned four 1,000 MW-scale pilot demonstration bases in its "Offshore Three Gorges" project, including Rudong, Dongtai, Dafeng and Qidong (see Fig. 2). Among the four, Rudong is the first base for construction [35]. Rudong is a county of Jiangsu and located at the southeastern part of Jiangsu. The total length of coastal line of Rudong reaches 106 km, accounted one ninth of that of Jiangsu province. Rudong is a plain land with a total sea area of more than 6,000 km^2 [36].

Due to Rudong's natural endowment of resources including wind energy, solar energy and tidal energy, Rudong formulated the plan of National Green Energy County in 2004 and the National Development of Reform and Commission (NDRC) awarded Rudong the title of Pioneer County of Building Green Energy in August 2004. Since then, various action plans and preliminary work of renewable energy projects have been formulated and carried out [37,38]. In 2009, *Master Plan of Wind Farms in Inshore and Tidal Zones in Rudong County* was completed and passed the review from the experts. The plan provides a clear guidance for the sound development of wind farms in offshore and tidal zones.

The achievement made by Rudong got the confirmation of leaders of the NDRC and the National Energy Administration. In September 9, 2009, China Energy Association awarded Rudong the title of Green Energy Center, and Rudong is the first to get the title within China [35]. In October 2010, Rudong was elected in the first group of National Green Energy Countries by the National Energy Administration of the NDRC. Rudong's 1,000 MW-scale wind farms are the first pilot demonstration base in Jiangsu Province. More than half of the 7 onshore and inshore wind power projects with total installed capacity 780 MW and total investment 10 billion yuan have been established, with accumulated electricity output 1.2 billion kWh. The layout of wind power in Rudong will include onshore, tidal and inshore zones, with total installed capacity 4,220 MW, in which onshore and tidal wind farms account for 1,720 MW and offshore wind farms 2,500 MW [38].

Besides Rudong, inshore wind farms are also under construction in Dongtai, Jiangsu. Dongtai has a coastline of 85 km with large space of mudflats, intertidal zones and shoals. The 1st phase wind power project of 200 MW is under operation while the 2nd phase project is under construction. The planned 3rd- and 4th-phase projects are 300 MW offshore wind power projects with total investment 6.6 billion yuan. It is estimated that by 2016, the total scale of wind power in Dongtai will reach 1,000 MW with annual electricity generation above 2 billion kWh [39].

7. Challenges of offshore wind power development in China

According to an official of the National Energy Administration of the NDRC, China is still short of the experience of building offshore wind power; offshore wind resource survey and evaluation, and localization of offshore wind turbine generator system is at the initial stage; the establishment of technology regulatory system of offshore wind power construction is in urgent need. Since January 2009, offshore wind power planning and building have been developed by related departments in China. With the promotion of the planning, the development of offshore wind power will enter the phase of demonstration and related administrative regulations will be established step by step. However, offshore wind power development is still at the stage from theory to practice. Since technology is not mature enough, it's not practical to develop offshore wind power in a large scale at the moment [5]. Due to the great differences between the development of onshore and offshore wind power, it should be more prudent in the development of offshore wind power, and demonstration projects which could accumulate experience in design, construction and operation management are necessary to form the management system and construction standards to guide the development of offshore wind power [40].

In general, there are three challenges for offshore wind power development in China.

(1) Key technologies and facilities related to wind power need further improvement. Although China have already had a group of large key manufacturing enterprises of wind power facilities, such as Sinovel, Goldwind Science and Technology, and Guodian United Power, there are still gaps between the wind turbines manufactured by China and those manufactured by countries which have reached the state-of-the-art level, in terms of product reliability, efficiency, and operating management. Some key technologies of wind power, such as the control system, have not been fully mastered, thus further technological R&D is needed. Compared with onshore wind power, there are more complex application environment and higher technological standards for offshore wind power, especially for large-scale development [41]. Therefore, to speed up the R&D and scale-production of large-scale offshore wind turbine generator system is of urgent need to develop offshore wind power in China [1].
(2) Issues of wind power grid integration and market absorption need to be solved. Up to mid March 2011, China's

accumulated wind power installation capacity has reached 44.5 GW. However, around 26–30% of wind power cannot be integrated to the power grid, which is much higher than the world average 10%. The issue of wind power grid integration has become the critical constraint of wind power development [42], and the key to promote offshore wind power development is to solve the problems of wind power grid integration and market absorption [41]. One reason for the difficulty of wind power grid integration may be the development of power grid lacking behind the rapid development of the wind farms [43]. Another possible reason is that at present, all electricity generation subsidies are given to wind power plants while there is no subsidy for power grid companies to compensate the loss of receiving unstable wind power, thus it's difficult to require power grid companies to accept wind power in a large scale [41]. To locally absorb electricity generated by offshore wind farms, non-grid-connected wind power generation theory is a good choice and pilot project has been set up (see Section 5.2), but more work needs to be done in applying the theory into practice.

(3) The economic benefits are not obvious. Currently, there's no unified and clear price setting method for the on-grid power tariff of offshore wind power, and the price is generally set by inviting public bidding. In the bidding of China's first offshore wind power concession projects, the on-grid power tariff of inshore wind power farm projects is around 0.74 yuan/kWh while that of intertidal wind power farm projects is around 0.64 yuan/kWh. In order to win the bidding at a low price, risk factors of the plans were reduced to the smallest by developers. However, the on-grid power tariff of offshore wind power farms is relatively low and close to that of onshore wind power farms, while the cost of the equipments and operation of offshore wind power is around twice that of onshore wind power [22]. Currently, per kilowatt investment of onshore wind farms has reached ten thousand yuan while that of the offshore wind farms has reached twenty thousand yuan [8,44]. Although from the long-term perspective, along with the technical progress in the design, layout, and installation optimization of turbines, the cost of offshore wind power is expected to reduce [31], the economic benefits for enterprises to invest in offshore wind farm construction are not obvious in the short term [8,45]. In addition, because the locations with abundant wind resources are limited, the first thing a wind farm company thinking of is to occupy the sites as much as it can. Therefore, thorough feasibility studies may be lacking due to the haste for the development, making some projects not economically viable [10].

8. Conclusions

Due to issues of pollution, sustainability, and climate change related to the consumption of fossil fuels, China has strived to develop new and renewable energy resources to meet its energy demand. Offshore wind power generation in coastal China has gradually become the focus of attention because it can make good use of the abundant natural resources and relieve the constraints of power shortage in coastal China. To promote the offshore wind power development, the central government of China has promulgated policies favorable for the sound development of offshore wind power. Pilot projects of offshore wind farms have been set up in Shanghai and Jiangsu and projects in other provinces in the coastal areas of China are under planning. However, challenges for offshore wind power development in China still exist, including weak R&D and manufacture capacities of wind power facilities, lacking of professional and inter-disciplinary talents, and the non-obvious economic benefits.

The development of the offshore wind industry worldwide has been largely driven by government polices and financial incentives [46–48]. Therefore, to achieve rapid and sound development of national or regional wind power industry, government policies and financial stimulation are needed. Recommendations for offshore wind power development are as follows [8,49–51]:

(1) identify offshore wind power development path and speed up the construction of demonstration projects;
(2) strengthen data gathering of offshore wind resources and the assessment of offshore risks;
(3) formulate economic policies to promote offshore wind power development;
    (1) formulate policies of reasonable offshore wind power price;
    (2) define reasonable market share of offshore wind power;
    (3) implement more preferential tax policies;
    (4) promote discount loan policies;
    (5) formulate more incentive measures to encourage the purchase of "green electricity";
(4) increase investment for initial work and R&D of offshore wind power;
(5) increase investment on power grid construction and promote smart power grid development;
(6) increase investment on R&D of projects using non-grid-connected wind power.

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